SCHOOL OF
CIVIL ENGINEERING

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JOINT HIGHWAY RESEARCH PROJECT

FHWA/IN/JHRP-89/14 - 2

Executive Summary - Final

DEVELOPMENT OF AN ASPHALTIC CONCRETE OVERLAY DESIGN PROCEDURE FOR RIGID PAVEMENTS IN INDIANA

Norman D. Pumphrey, Jr.
Thomas D. White

PURDUE UNIVERSITY

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DESIGN PROCEDURE FOR RIGID PAVEMENTS IN INDIANA

Executive Summary

TO: Harold L. Michael, Director
Joint Highway Research Project

July 7, 1989

Project: C-36-55G

FROM: Thomas D. White, Research Engineer
Joint Highway Research Project

File: 2-12-7

Attached is the Final Report on the HPR Part II study titled, "Development of an Asphaltic Concrete Overlay Design Procedure for Rigid Pavements in Indiana." This study presents the results of a study that evaluated nondestructive testing equipment and utilized data collected from the existing highway system to develop a proposed overlay design procedure for rigid pavements.

As the result of the complex performance of asphalt overlays of rigid pavements design procedures have been developed to characterize the structural or functional performance. Guidance based on fatigue criteria is utilized to delineate application of the two performance regimes.

This report is forwarded to INDOT and FHWA in fulfillment of the objectives of the study.

Sincerely yours,

Thomas D. White

Thomas D. White
Research Engineer

TDW/cah

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DEVELOPMENT OF AN ASPHALTIC CONCRETE OVERLAY DESIGN PROCEDURE FOR RIGID PAVEMENTS IN INDIANA

Executive Summary

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16. Abstract

A overlay study was conducted of thirty jointed reinforced concrete pavements (JRCP) and thirteen continuously reinforced concrete pavements (CRCP). These pavements were selected from the Indiana primary highway system based on an experimental design for levels of major factors affecting pavement performance. An analysis was made of pavement deflection; condition; serviceability; materials; thicknesses; truck traffic; latest overlay thickness; age; climate zone and subgrade type, density and moisture content. Initially, a rational analysis was planned using a back calculated material properties as suggested in the 1986 AASHTO Design Guide. However, this approach was not successful and alternate analysis procedures were utilized.

The performance of asphalt overlays of concrete pavement proved to be complex. Fortunately, analysis of the data base built using experimental design techniques helped to explain this complex performance. Based on the performance data several performance regimes were characterized. For example, increased overlay thickness for jointed concrete pavements on stiff foundations was characterized by a relation using a PCI subset of cracking distresses.

A statistical analysis was performed on the CRCP pavement data, and an overlay model was developed. However, because of the limited range in thickness, truck traffic, etc. the equation should be used only as a guide for determining overlay thickness.

Two statistical models were developed for the JRCP sections. The first is a structural model, to be used for thin to medium thick (6" to 9") PCC pavements with thin AC overlays. The second is a functional model, to be used with thick (>9") PCC pavements or any PCC pavements with thick (>5") AC overlays. A procedure has been formulated for determining which of these equations is applicable for particular AC/PCC thickness combinations.

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Executive Summary

Development of an Asphaltic Concrete Overlay
Design Procedure for Rigid Pavements in Indiana

The road and highway system in Indiana consists of 91,500+ miles of public streets and highways. Of this mileage, approximately 11,350 centerline miles are maintained by the Indiana Department of Transportation (INDOT). Sixty percent of the total vehicle miles traveled traverse this state-maintained mileage. The bulk of these vehicle miles may be found on the Federal-aid Interstate (FAI) and Primary (FAP) systems, which account for approximately 6,200 of the 11,350 centerline miles.

Within the 6,200 centerline miles contained on the FAI and FAP systems in Indiana, 1732 different pavement sections, varying in length from one-quarter to several miles, were identified. Of this total, 1147 sections (9700 lane miles) consisted of either jointed reinforced concrete pavements (JRCP) or JRC composite pavements (i.e., asphaltic concrete over JRCP). The composite pavements comprise approximately 72% of these JRCP sections, many of which have been overlaid several times since the original JRCP construction. One hundred and seven (107) sections (1370 lane miles) were either continuously reinforced concrete pavements (CRCP) or CRC composite pavements.

The overlay of rigid or composite pavements with asphaltic concrete (AC) is, by far, the most common overlay technique used by INDOT. Better understanding of overlay thickness requirements and performance was identified by INDOT as a high priority research topic. As a result, INDOT through the Joint

Highway Research Project (JHRP) funded research in the Purdue University School of Civil Engineering to develop overlay requirements for concrete pavements in Indiana. The results of this research are the subject of this report.

Overview of Research

Initially, an inventory of the pavement sections contained on the FAI and FAP systems was completed. The following data were collected on each section from various INDOT sources: pavement cross section types and thicknesses, traffic, climate zone, and overlay age. This information was used to select the possible sections that would be tested. Each potential test section was visited by project personnel, and possible problems that could cause the site to be eliminated, such as poor sight distance or steep grade, were noted. Other data, such as subgrade type and strength, were desired for the section selection process but were not available.

An experimental design was developed for levels of the major factors that would be expected to affect pavement performance. The experimental design was structured such that thirty JRC and JRC composite pavements and thirty CRC and CRC composite pavements were required. Unfortunately, CRC and CRC composite pavements in Indiana have fairly uniform traffic and thicknesses. Therefore the cells in the experimental design could not be completely filled. After study thirteen CRCP were identified with limited variation of factor levels and were tested.

Esch section of pavement tested was approximately 1250 feet long.

Present serviceability index (PSI) was obtained for each section from INDOT. Pavement condition index (PCI) was calculated from a field survey of pavement distresses on each section. Subgrade information was gathered from each section from soil borings taken from two borings within the 1250′ pavement section.

Nondestructive testing (NDT) was conducted on each test section. On most sections, four different NDT devices were used:

1. Dynaflect. A Dynaflect and technician were made available by the InDOT Research Division.

2. Road Rater 400 (RR400). An RR400 and technician were made available by the Kentucky Transportation Research Center at the University of Kentucky.

3. Road Rater 2000 (RR2000). An RR2000 and technician were made available from the Kentucky Department of Transportation.

4. Dynatest Falling Weight Deflectometer (FWD). The U.S. Army Corps of Engineers Waterways Experiment Station loaned the project team an FWD. The INDOT provided a technician to operate the device.

NDT testing was conducted in two four-week test periods in 1986 — spring and summer/fall — so that the seasonal variations could be estimated. Each pavement test section was tested at six locations by all four NDT device. Pavement surface temperature was measured at the test site and five-day air temperature history preceding testing was obtained from the National Oceanic and Atmospheric Administration (NOAA). This temperature information was used to

determine the average pavement temperature in the AC layer overlying the rigid pavement. Deflection and AC layer stiffness could then be adjusted to a "standard" pavement temperature for comparison.

Data from the pavement sections were analyzed using both empirical and structural methods for determining required AC overlay thickness. In the empirical method, statistical analyses were used to determine which factors could be used to adequately predict AC overlay thickness. The 1986 AASHTO Guide for Design of Pavement Structures was used to determine the structural overlay needs of "semi-rigid" concrete pavements (ones showing structural distress such as transverse and longitudinal cracks) and to determine the AC overlay requirement to reduce reflective cracking.

Empirical Data Analysis

The original statistical design variables were climate, traffic, ratio of most recent overlay thickness to total pavement thickness, and portland cement concrete (PCC) thickness. In addition to these factors, data were collected on several other pavement-related factors which were not originally considered as primary factors in designing the experimental design:

1. Age of most recent overlay
2. Asphalt base thickness (asphaltic concrete below newest overlay and above the PCC)
3. Subbase thickness and type

4. Subgrade dry unit weight, moisture content, and estimated CBR

5. Distress survey data

6. Present Serviceability Index (PSI)

7. Pavement deflections

8. Pavement surface temperature.

CRCP Model. A model was developed to predict the overlay required for CRC pavements.

$$OLAY = -0.0138 + 1.264(PSI) + 0.0677(CBR) \quad (1)$$

where OLAY = required thickness in inches of AC overlay (experience has shown that a minimum 3" overlay directly on concrete is required)

PSI = terminal present serviceability index

CBR = estimated California Bearing Ratio of subgrade in %

One of the problems with this equation is that the range for the variables is very small because of the relative homogeneity of the pavement factor levels. The independent variables and their ranges of applicability (inference) are

1. PSI - 2.8 through 3.9

2. CBR - 5% through 14%

The CRCP regression model can be used as a guide for determining AC overlay thickness. However, because of the problems previously mentioned — particularly the small number of test sections and the narrow range of applicability -- it should be used with caution. Alternatively, the JRCP model (which follows) could be used as a guide for AC overlay of CRCP sections, as

long as the designer is aware that this model was developed for JRC and not CRC pavements.

JRCP Model. Concern developed during the JRCP model development that more than one relationship might be required for JRC pavements. A structural relation was considered possible for thinner PCC pavements with relatively thin overlays and, possibly, for thick PCC pavements with no overlay. On the other hand, thick PCC pavement with thicker overlays and good subgrade support would not generally be structurally deficient. Ultimately, two separate models resulted — one primarily structural and one primarily functional.

Many regression models were investigated and sensitivity analyses run to locate the "best" model(s) for JRC pavements. The equation that was accepted as the structural/empirical design model is a hybrid of centered and unadjusted terms with both the structural and performance characteristics represented.

$$\begin{aligned} OLAY = 4.407 &- 0.410(ASPTHK) + 1.021(NPSI) \\ &- 0.088(XTRKPSI) - 1.735(NPSI)^2 \end{aligned} \qquad (2)$$

where OLAY = required thickness in inches of AC overlay

ASPTHK = total thickness in inches of AC currently on the PCC (before overlay)

NPSI = centered value of terminal present serviceability index (PSI) desired for the overlay (or PSI - 3.283)

XTRKPSI = two-factor interaction between total trucks (TOTTRK) in millions that will pass over the new overlay during its lifetime and NPSI (or TOTTRK * NPSI)

where $TOTTRK = \dfrac{(\text{Trks per day})(365)(AGE)}{1{,}000{,}000}$

AGE = age in years that the new

overlay should last

The independent variables and their ranges of applicability are

1. Asphalt thickness (inches) - 0" through 8" (experience has shown that a minimum 3" overlay directly on concrete is required)

2. PSI - 1.7 through 4.5

3. Trucks per day - 400 through 5000 (or TOTTRK - 0.15 million through 25 million)

4. Age - 0 years to 15 years

Careful consideration of the performance characteristics of pavements tested suggested that the controlling type of performance transitioned from structural to functional performance. After reflection, the primary measure adopted to determine where this change could occur was the flexural stress at the bottom of the PCC. It was reasoned that if this stress is large enough for fatigue to be a factor, then the structural equation above should be used. If the flexural stress is low so that fatigue would not be considered a factor, a functional relationship is more appropriate. Figure 1 was developed using a fatigue analysis and provides guidance on when an empirical model should be used.

A functional model was developed to design AC overlays for JRC or JRC composite pavements that are structurally sound but which require an overlay because of unacceptable performance.

$$\begin{aligned} OLAY = 0.712 &+ 0.0118(TOTTRK)^2 + 0.000153(PCI)^2 \\ &+ 0.00329(AGE)^2 + 0.393(TYPE) \end{aligned} \quad (3)$$

where OLAY = required thickness in inches of AC overlay

TOTTRK = the total trucks in millions that will pass over the new overlay in its lifetime (see equation 4.3 for the formula for calculating total trucks)

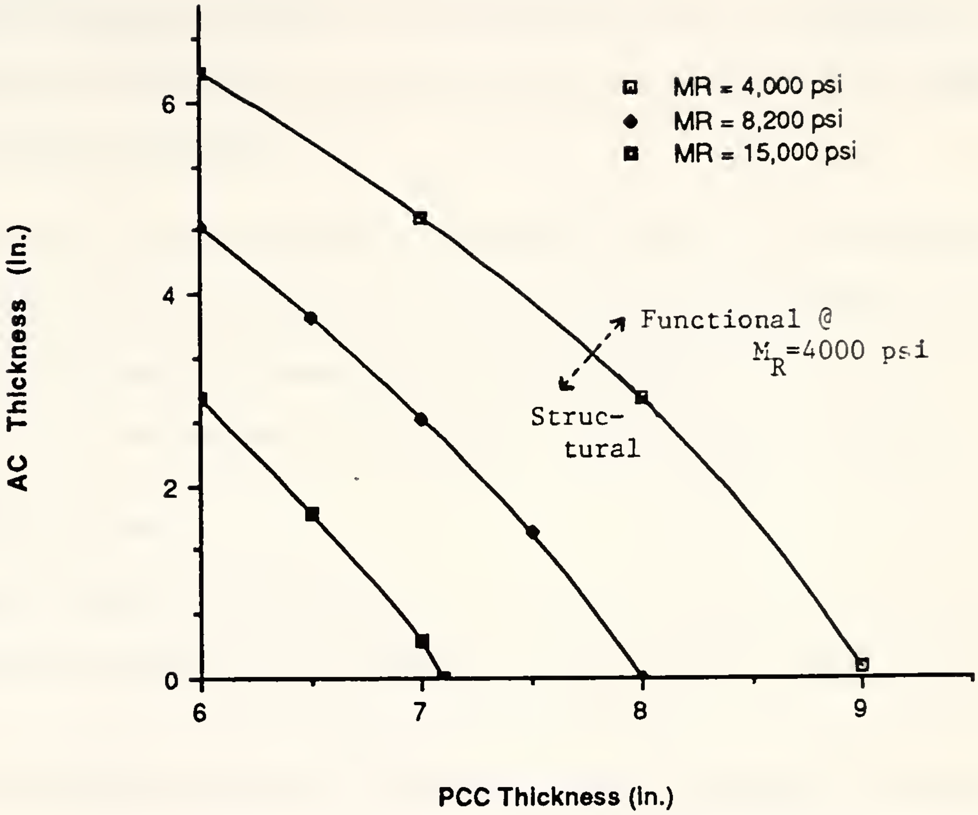

Figure 1 PCC Versus AC Overlay Chart for Determining Appropriate Empirical Equation.

PCI = pavement condition index (33)

AGE = design lifetime in years of the proposed overlay

TYPE = type of pavement (1 = JRCP or composite JRCP, 0 = AC)

Note that the TYPE variable was found to be significant and was included in the model. Thus, this equation can be used for AC pavements as well as JRCP to estimate AC overlay thickness.

The applicability range for which the functional model is statistically sound is as important in this model as it was for the structural model. The independent variables and their ranges of applicability are

1. Trucks per day - 100 through 3000 (or TOTTRK - 0.15 million through 11 million)
2. PCI - 29 through 100
3. AGE - 0 years through 15 years
4. TYPE - When analyzing JRC or JRC composite pavements, TYPE always equals 1

Because of the strong statistical base of the data, reliability concepts can be developed for the above relations developed. As a basic definition for this project, reliability is the probability that an overlay thickness will perform as expected subject to basic criteria from which it was developed.

Overlay thickness determined by equations 1, 2, and 3 is essentially the mean of the sample data from which it was developed. As such, the reliability is 50% that the pavement will perform as expected. Tables 1, 2, and 3 show thicknesses that should be added to the value calculated from equations 1, 2, and 3, respectively, to achieve higher reliability levels.

Table 1 Additional Overlay Thickness for Various Reliability Levels -- Equation 4.1 (CRCP Model).

Reliability (%)	Additional Thickness (in.)
99	2.8
95	2.0
90	1.5
80	1.0
70	0.6
60	0.3

Table 2 Additional Overlay Thickness for Various Reliability Levels -- Equation 4.3 (JRCP Structural Model).

Reliability (%)	Additional Thickness (in.)
99	1.8
95	1.3
90	1.0
80	0.7
70	0.4
60	0.2

Table 3 Additional Overlay Thickness for Various Reliability Levels -- Equation 4.4 (JRCP Functional Model).

Reliability (%)	Additional Thickness (in.)
99	3.0
95	2.1
90	1.7
80	1.1
70	0.7
60	0.3

AASHTO Guide Methods

Two methods for normal structural overlay design are described in the AASHTO Guide. Method 1 involves using backcalculation techniques and NDT load and deflection readings for determining modulus values of the various layers in a pavement cross section. Method 2 uses the NDT load and maximum temperature-adjusted deflection to determine the structural capacity of all layers above the subgrade. The NDT load and an unadjusted deflection reading at a substantial distance from the NDT load is used to estimate the subgrade modulus. In both methods, the structural number (SN) and associated required overlay thickness can be determined.

Unfortunately, neither method could be used exclusively, so a combination of methods were used. Method 1 was employed to determine the subgrade modulus. Method 2 was then used to find the effective structural number of all layers above the subgrade using the subgrade modulus found previously.

This method is only acceptable for flexible pavements and for rigid pavements showing signs of structural distress ("semi-rigid" pavements). It cannot be used if a pavement is failing functionally with no signs of structural distress.

The AASHTO Guide also discusses several overlay design methods used to reduce reflective cracking from the rigid pavement layer through the AC overlay. Two of these methods — the minimum thickness and the break and seat approaches — were evaluated.

Comparison

For several test sections the required overlay was calculated using the empirical, structural, and reflective cracking techniques. This process was not a check using the exact data from which the empirical method was formulated. The AC overlay thickness calculated for each section was that required to be placed on the existing pavement structure. In essence, the sections were looked at in terms of future performance and not in terms of past performance as was done in the model formulation.

CRCP Test Sections

An analysis was made of four CRC pavement sections with PSI values less than or equal to 3.0. For each of these pavements, the overlay thickness was calculated using the empirical design method (equation 1), the AASHTO Design Guide structural method, and the AASHTO Design Guide Procedure for two reflective cracking techniques — the minimum AC thickness and the break and seat approaches.

Empirical Method. As discussed previously, the data set was uniform in terms of existing PCC thickness and existing AC overlay thickness and results should be used with caution. Design inputs into equation 1 and calculated AC overlay thicknesses are shown in Table 4.

Subgrade CBR for these four sections does not vary much. Consequently the calculated overlay thicknesses is approximately the same for all sections considered. As pointed out this overlay value represents a 50% reliability level. Table 1 should be used to increase the overlay thickness and, thus, the reliability level of the overlay performance.

Table 4 Overlay Thickness Required on Selected CRC Pavement Sections Using Empirical Model.

Section No.	Terminal PSI	Subgrade CBR	PSI Now	Overlay Req'd
C-01	2.5	6	2.8	3.55"
C-02	2.5	5	2.8	3.48"
G-01	2.5	8	2.8	3.69"
S-03	2.5	7	3.0	3.62"

Table 5 Overlay Thickness Required on Selected CRC Pavement Sections Using AASHTO Design Guide.

Section No.	Structural Thickness (in.)	Reflective Cracking	
		Min. Thickness (in.)	Break & Seat Thickness (in.)
C-01	-3.95	4.0	-0.08
C-02	2.53	4.0	8.17
G-01	-5.21	4.0	4.78
S-03	-7.77	4.0	5.25

AASHTO Design Guide. The AASHTO structural design procedure and two reflective cracking reduction techniques are investigated to determine required AC overlay thickness of PCC. The resulting AC overlay thicknesses may be found in Table 5.

In three of the four test sections, the normal structural overlay method resulted in a negative required AC overlay thickness, indicating that performance failure superseded the structural needs of the pavement. However, a 2.5-inch overlay was predicted for the fourth section (C-02) to provide additional structural support for the traffic projected over the 10-year design life.

Table 5 shows the AC overlay thicknesses required for the two reflective cracking procedures. The first approach (minimum AC thickness) assumes that the underlying slabs are properly repaired and are essentially intact before the overlay is placed. The required overlay is often thick, particularly if the PCC slabs are long and if the temperatures are drastically different between the warm and cool seasons for the given pavement location.

A minimum asphalt thickness required to retard reflective cracking in the CRCP was calculated for a crack spacing (slab length) of 18" to 36". For these conditions the required minimum thickness on each of the pavement test sections is four inches. This thickness should be sufficient for a CRCP which has been properly repaired and which was initially constructed to support the traffic loads. However, four-inch overlays placed on properly repaired CRC pavements in Indiana prior have performed structurally with varying degrees of success. For instance, punchouts have occurred due to inadequate pavement

cross section or lack of uniform subgrade support.

JRCP Test Sections

Ten JRCP pavement test sections with PSI values less than or equal to 2.8 were analyzed.

Empirical Method. Results of the empirical analysis (equations 2 and 3) are shown in Table 6. The predicted thicknesses using the empirical equation are thin for AC overlays of PCC pavement. However, two items must be considered when analyzing the predicted thicknesses. First, the value calculated is that which gives a reliability of 50%. Tables 2 and 3 must be used for higher reliability. Secondly, a design to reduce the rate of reflective cracking in the asphalt overlay is not considered in this model. The required AC thickness to reduce reflective cracking will likely be greater than that predicted by this equation.

AASHTO Design Guide. Results of the AASHTO structural and reflective cracking calculations are shown in Table 7. In all ten cases, the required AC overlay for the structural analysis is a negative number. This indicates that all of the pavement sections considered are structurally sound. The problem with this analysis and the results obtained is that the analysis assumes full foundation support. However, temperature, moisture and erosion could create a loss of support which would reduce the structural capacity.

For sections C-07 and F-03, the calculated structural overlay is near zero, indicating that the current pavement cross section is sufficient. The

Table 6 Overlay Thickness Required on Selected JRC Pavement Sections Using Empirical Models.

Sect. No.	Subgr. CBR	AC (in.)	PCC (in.)	Term. PSI	Term. PCI	Trucks per Day	O´lay Life	PSI Now	Eq´n Type*	O´lay Req´d
C-04	3	3.7	8.2	2.5	35	910	10	2.8	F	1.75"
C-06	10	0.0	7.1	2.5	35	3105	10	1.7	S	3.32"
C-07	8	4.2	6.8	2.5	35	3105	10	2.4	F	3.14"
F-03	5	6.8	7.6	2.5	35	885	10	2.6	F	1.74"
F-08	40	2.8	9.3	2.5	35	1744	10	2.8	F	2.10"
F-10	5	5.6	7.0	2.5	35	3302	10	2.6	F	3.34"
F-12	6	3.2	9.1	2.5	35	3047	10	2.7	F	3.08"
G-03	6	5.4	7.0	2.5	35	1350	10	2.5	F	1.91"
L-08	25	0.0	9.4	2.5	35	1775	10	1.9	F	2.12"
V-02	5	5.1	8.8	2.5	35	796	10	2.6	F	1.72"

* S = structural equation, F = functional equation

Table 7 Overlay Thickness Required on Selected JRC Pavement Sections Using AASHTO Design Guide.

Section No.	Structural Thickness (in.)	Reflective Cracking	
		Min. Thickness (in.)*	Break & Seat Thickness (in.)
C-04	-1.75	4.5	5.11
C-06	-3.17	8.0	3.02
C-07	-0.01	8.0	4.99
F-03	-0.36	8.0	2.94
F-08	-6.79	8.0	2.44
F-10	-1.22	8.0	4.86
F-12	-14.43	8.0	3.18
G-03	-1.53	8.0	2.70
L-08	-3.66	7.0	1.96
V-02	-8.73	4.5	6.36

* AASHTO recommends using another technique, because reflective cracking cannot be reduced by increasing the overlay thickness over these 40′ slabs with the existing maximum annual temperature differential. However, many of the 40′ slabs on these sections have cracked at about midslab.

calculate overlay thicknesses for the remaining pavement sections are negative indicating that they are structurally overdesigned and theoretically should last well past the expected design period.

Reflective cracking mitigation techniques were evaluated. From the analysis seven of the ten pavement sections required a minimum AC overlay thickness of eight inches. In fact, because of the overlay thickness required the AASHTO Guide recommends cracking and seating as an alternative.

The design technique used for cracking and seating generally requires a thickness of AC overlay that is less than the thickness to mitigate reflective cracking as shown in Table 7.

Conclusions and Recommendations

After completing the overlay study, several major conclusions and recommendations for further study were developed:

1. Existing Indiana CRC pavements do not have significant factor level variation to develop an adequate study of CRCP overlay requirements. The model developed needs more supporting data and refinment before it can be used with confidence.

   Additional CRC pavements are currently being overlaid with AC thickness greater than those found in this study. In several years, a variety of CRC composite pavements with more widely distributed overlay ages, thicknesses, and total truck traffic will be available for testing. A follow-up to this study that considers only CRC pavement would be

desirable.

2. Other than for the subgrade, the modulus backcalculation techniques using elastic layer theory did not prove to be adequate for computing the modulus values for the various pavement layers. Even after using methods for estimating and fixing the modulus for the AC pavement on top of the JRCP and recalculating the PCC modulus, only 30% of the PCC modulus values were within what is considered to be a normal range. Additional work is necessary to develop new or to refine old backcalculation methods.

3. Most failures of rigid or composite pavements would not be structurally related if the contact between the PCC and the subgrade/subbase could be properly maintained. In all cases analyzed using the AASHTO structural design method, the test pavements should last an additional ten years under the projected 18-kip EAL loadings. On these pavements that are structurally sound but functionally deficient, milling of the existing AC pavement surface material for possible use in a recycled overlay should be considered.

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